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Rehabilitation with forage grasses of an area degraded by urban solid waste deposits

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ABSTRACT - Dry matter yield and chemical composition of forage grasses harvested from an area degraded by urban solid waste deposits were evaluated. A split-plot scheme in a randomized block design with four replicates was used, with five grasses in the plots and three harvests in the subplots. The mineral content and extraction and heavy metal concentration were evaluated in the second cut, using a randomized block design with five grasses and four replicates. The grasses were *Brachiaria decumbens* cv. Basilisk, *Brachiaria ruziziensis, Brachiaria brizantha* cv. Marandu and cv. Xaraés, and *Panicum maximum* cv. Tanzânia, cut at 42 days of regrowth. The dry matter yield per cut reached 1,480 kg ha^{-1}; the minimum crude protein content was 9.5% and the average neutral detergent fiber content was 62.3%. The dry matter yield of grasses was satisfactory, and may be an alternative for rehabilitating areas degraded by solid waste deposits. The concentration of heavy metals in the plants was below toxicity levels; the chemical composition was appropriate, except for phosphorus. The rehabilitated areas may therefore be used for grazing.

Key Words: *Brachiaria spp.*, dry matter yield, heavy metals, mineral extraction, Tanzania grass

Introduction

The development model in modern society generates high production and consumption levels, which cause serious basic sanitation issues, especially around household sewage and waste (Braga et al., 2002). It has been estimated that over 65% of the waste generated in Brazil is stored inadequately (IBAM, 2004).

It is often impossible to fully rehabilitate an ecosystem after a first attempt; the impacting agents are mitigated initially by being covered with soil (Rovedder & Eltz, 2008). Revegetation improves water retention and infiltration, increases the organic matter content, and fosters biological activity (Klamt & Schneider, 1995).

It is important to choose the right species for recovering degraded areas so that positive results are attained. These species need to be sufficiently robust to establish themselves easily in unfavorable environments, to compete against other species, and to develop rapidly (Dias & Griffith, 1998; Resende & Kondo, 2001). Forage grasses have a high tillering capacity, which increases the sustainability of a given system by producing significant amounts of biomass and organic matter, and by growing roots that provide superior mechanical support for soils (Pereira, 2006).

Heavy metals are highly reactive and accumulate in biological organisms – which cannot eliminate these substances. Heavy metals include Pb, Cd, and Cr, which are toxic for plants when over critical levels in soils, and Cu, Zn, and Ni, which are essential for most plants. Co is also beneficial for plant development (Simão & Siqueira, 2001). Heavy metals may accumulate in plants without toxicity symptoms or loss of crop productivity (Jeevan Rao & Shantaram, 1996).

Thus, the purpose of this study was to evaluate dry matter yield, chemical composition, mineral content and extraction, and heavy metal concentrations in five forage grasses (*B. decumbens* cv. Basilisk, *B. ruziziensis*, *B. brizantha* cv. Marandu and cv. Xaraés, and *P. maximum* cv. Tanzânia) in an area degraded by decomposed urban solid waste.

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Material and Methods

The study was carried out on a recovering uncontrolled landfill in the facilities of the Campus JK of the Universidade Federal dos Vales do Jequitinhonha e Mucuri, in Diamantina, Minas Gerais.

The climate is typically tropical (Cwb in the Koppen classification), the mean annual rainfall ranges from 1,250 to 1,350 mm, and the mean annual temperature ranges from 18 ºC to 20 ºC; the relative moisture of the air is almost always high – annual mean of 70.6% (Neves et al., 2005).

The soil was a typical Yellow Dystrophic soil (EMBRAPA, 2006), with 58, 16, and 26 dag kg^{-1} of sand, silt, and clay, respectively. It should be noted that the soil has been significantly altered by human activities – it had been significantly upturned and other soils had even been unloaded on the site.

The declivity of the experiment area was 4%, and it had been used as an uncovered urban solid waste deposit from 1993 to 2003; revegetation did not occur spontaneously after the area was deactivated; thus most of the soil surface remained exposed.

On November 19, 2007, soil preparation was started by applying 1.0 t ha^{-1} of dolomitic limestone followed by plowing. The limestone dose was based on soil analysis (Table 1) and the requirements of forage grasses, as recommended by Ribeiro et al. (1999).

On January 23, 2008, phosphate and potassium fertilizers were added as follows: 90 kg ha^{-1} of P_2O_5 as simple superphosphate, and 40 kg ha^{-1} of K_2O, as potassium chloride, incorporated in two disk harrows. Dosages were calculated according to fertilizer recommendations for pastures (Ribeiro et al., 1999), soil analysis, technological level (medium), and soil nutrient availability (low). Next, the grasses were sown.

The cultural value of *Brachiaria* seeds was 72%, using 7 kg ha^{-1} seeding rate, and the cultural value of Tanzânia seeds was 56%, using 5.4 kg ha^{-1} seeding rate. On March 7, 2008, top-dressing fertilization was carried out – 50 kg ha^{-1} of N, 40 kg ha^{-1} of K_2O, and 2 kg ha^{-1} de Zn; the respective sources were ammonium sulphate, potassium chloride, and zinc sulphate.

The dry matter yield - expressed in kg ha^{-1} as the product of green mass in the useful area of each plot and the dry matter content of each sample per plot - and the dry matter, crude protein, neutral detergent fiber (NDF), and acid detergent fiber (ADF) content were evaluated in a split-plot scheme in a randomized block design. The five grasses were cultivated on plots and the three harvests on subplots, with four replicates. Cuts were done every 42 days.

On October 22, 2008, uniform cutting was achieved with a brush-cutter at 20 cm above the soil level for a larger plant cover volume over this degraded area. The biomass cutwas removed and equivalent dosages (60 kg ha^{-1} of N, and 60 kg ha^{-1} of K_2O) were applied to all plots, as recommended by Ribeiro et al. (2009); these doses were repeated following the 1st and 2nd cuts.

Forage grasses were evaluated at every 42 days after regrowth and harvested at 20 cm height over the level of the soil; cuts were done on December 1, 2008, January 12, 2009, and February 27, 2009.

The consolidated rainfall and the mean maximum and minimum temperatures across the three growth periods were respectively 294.8 mm, 20.2 °C and 19.2 ºC; 536.0 mm, 19.4 °C and 18.4 °C; and 232.6 mm, 20.6 °C and 19.5 °C.

Grass samples were taken from a 2.25 m^2 area used in each plot and then weighed. The dry matter yield per hectare was calculated based on the biomass weight of the useful area. Subsamples of plants from each plot were weighed and pre oven-dried (60 ºC, 72 hours), as described by Silva & Queiroz (2002). Samples were then ground in a Willey grinder with a 1-mm sieve and stored in closed plastic recipients.

The minerals phosphorous (P), nitrogen (N), potassium (K), calcium (Ca), magnesium (Mg) and the heavy metals chromium (Cr), zinc (Zn), nickel (Ni), cobalt (Co), copper (Cu), and cadmium (Cd) were evaluated only in plant samples taken from the 2nd cut, by applying a randomized block design using five grasses and four replicates.

The dry matter, nitrogen (N), crude protein, NDF, and ADF contents were measured according to Silva & Queiroz (2002). Phosphorous (P), potassium (K), calcium (Ca), and magnesium (Mg), were analyzed according to EMBRAPA (1997). The heavy metals (Cr, Cu, Zn, Cd, Pb, Ni, and Co) were measured as described by Malavolta et al. (1997).

Table 1 - Results of the soil chemical analysis, at 0 to 20 cm depth, in the experiment area before planting of forage grasses

OM	pH	H+Al	Al	Ca	Mg	SB	t	T	P	K	m	V
dag kg^{-1}	H_2O	$cmol_c dm^{-3}$							mg dm^{-3}		%	
0.1	5.5	1.9	0.2	0.6	0.2	0.8	1.0	2.7	0.8	17	19	31

OM - organic matter; pH - hydrogen ionic potential in water; H + Al - hydrogen plus aluminum; Al - aluminum; Ca - calcium; Mg - magnesium; SB - sum of bases; t - effective cationic exchange capacity; T - cationic exchange capacity at pH 7.0; P - phosphorous; K - potassium; m - aluminum saturation; V - base saturation.

Analysis of variance and the Tukey test ($P<0.05$) were applied to the data; the SAEG software (Sistema para Análises Estatísticas, versão 9.1) was used for this purpose. Descriptive statistics were applied to the variables Cu and Cd, which did not meet the basic assumptions of normality and variance homogeneity.

Results and Discussion

The total dry matter yield did not differ between grasses; for *B. ruziziensis*, Marandu, Xaraés, Tanzânia, and Basilisk, the yields were respectively 2,753.62; 3,353.62; 3,589.81; 3,444.88, and 3,610.53 kg ha^{-1}; the overall mean was 3,350.49 kg ha^{-1}. Visual observation showed that all forage grasses adequately covered the soil.

In the soil chemical analysis after implantation of forage grasses, positive effect of vegetation, soil correctors, and fertilizers could be observed (Table 2). After the experiment, the dry matter yield increased in the soils, and the fertility level increased, as evidenced in an increased pH, decreased potential acidity, and increased nutrient availability (especially P and K). There were also positive effects on the cation exchange capacity and base saturation.

The dry matter yield per cut and the content of dry matter, crude protein, and NDF did not differ between grasses; these indicators did vary with cuts, except for NDF (Table 3) – it remained constant for grasses and cuts.

Higher dry matter yields were attained in the second and third cuts, which were similar (Table 3). The lowest dry matter yield in the first cut may have been caused by lack of rain two weeks after fertilization.

The dry matter content was higher in the third cut (26.01%) compared with the first (22.27%) and second cuts (22.98%), which were similar (Table 3). These values are within the normal range for forage grasses.

The highest crude protein content (26.06%) was measured in the first cut, and the lowest (9.46%) in the third cut; a middle value was found in the second cut (13.65%) (Table 3). The higher crude protein content in the first cut may have been due to N concentration in the lowest dry matter yield. Crude protein contents were higher than the 7% critical level, which is commonly cited as the minimal amount ruminants require to maintain the rumen microbiota. Botrel et al. (1999) recorded crude protein levels of 12.3, 10.4, and 8.6 %, respectively for *B. brizantha*, *B. decumbens*, and *B. humidicola*, at 35 days growth in the wet season in southern Minas Gerais.

The NDF content did not differ between cuts; the mean value of three cuts was 62.26% (Table 3). The NDF content is an important parameter for defining forage quality; values

Table 2 - Results showing the soil chemical analysis in the experiment site after implantation of forage grasses, in 0-10- and 10-20-cm layers

Grass	OM	pH	H+Al	Al	Ca	Mg	SB	t	T	P	K	m	V
	dag kg^{-1}	H_2O	$cmol_c dm^{-3}$							mg dm^{-3}		%	
						0-10 cm							
Basilisk	0.6	5.6	1.4	0.4	0.6	0.2	1.0	1.4	2.4	1.8	62	29	41
B. ruziziensis	0.9	5.5	1.4	0.3	0.4	0.2	0.8	1.1	2.2	2.5	62	28	35
Marandu	0.6	5.8	1.5	0.2	0.6	0.3	1.0	1.2	2.5	1.4	47	16	40
Xaraés	0.9	5.4	1.5	0.5	0.7	0.2	1.1	1.6	2.6	2.2	67	32	42
Tanzânia	0.9	5.9	1.5	0.2	0.5	0.3	0.9	1.1	2.4	2.1	56	17	39
						10-20 cm							
Basilisk	0.7	5.8	1.0	0.3	0.5	0.3	0.9	1.2	1.9	1.7	49	24	48
B. ruziziensis	0.3	5.6	1.0	0.3	0.4	0.2	0.7	1.0	1.7	0.9	38	30	41
Marandu	0.8	6.1	1.0	0.2	0.6	0.2	0.9	1.1	1.9	1.0	36	18	47
Xaraés	0.8	5.4	1.4	0.4	0.6	0.3	1.1	1.5	2.5	2.2	65	27	43
Tanzânia	0.7	5.8	1.1	0.2	0.7	0.3	1.1	1.3	2.2	1.2	44	15	50

OM - organic matter; pH - hydrogen ionic potential in water; H + Al - hydrogen and aluminum; Al - aluminum; Ca - calcium; Mg - magnesium; SB - sum of bases; t - effective cation exchange capacity; T - cation exchange capacity at pH 7.0; P - phosphorous; K - potassium; m - aluminum saturation; V - base saturation.

Table 3 - Dry matter yield per cut (kg ha^{-1}) and dry matter, crude protein and neutral detergent fiber content (%) (means of the cultivars Basilisk, Marandu, Xaraés, Tanzânia and *B. ruziziensis*) and coefficients of variation (CV)

	1st cut	2nd cut	3rd cut	Mean	CV
Dry matter yield	441.46b	1,484.55a	1,424.48a	-	27.51
Dry matter	22.27b	22.98b	26.01a	-	7.81
Crude protein	26.06a	13.65b	9.46c	-	13.25
Neutral detergent fiber	60.72a	61.95a	64.11a	62.26	13.35

Means followed by the same letter on rows did not differ ($P>0.05$) by Tukey test.

over 60% correlate negatively with voluntary consumption of dry matter by animals (Van Soest, 1994). NDF levels are rarely below 60% in tropical climate forage grasses.

Acid detergent fiber content results were affected by the interaction and cuts of grasses. There were no variations between grasses in the first cut (Table 4) – the mean was 26.85%. Cv. Basilisk had a higher ADF content in the second cut (33.68%), which differed from *B. ruziziensis* (26.66%). In the third cut, *B. ruziziensis* had lower ADF content (24.06%) than Marandu (30.33%), Xaráes (32.17%), and Tanzânia (31.81%).

Cultivar Basilisk had the highest ADF content in the second cut (33.68%); cv. Tanzania had the lowest content in the first cut (25.17%). The ADF did not vary between cuts in *B. ruziziensis* and the *B. brizantha*, Marandu, and Xaraés cultivars; the mean values were respectively 25.58; 29.71, and 30.46% (Table 4). Costa et al. (2007) found ADF contents of 34.0 (30 days) and 36.0% (60 days) in cv. Marandu.

Dry matter yield did not differ between grasses; its mean value was 1,484.55 kg ha^{-1}, following a 42-day growth period (Table 5). There were differences in nitrogen (N) and potassium (K) contents between grasses. There were no differences between forage grasses in the content of phosphorous (P), calcium (Ca), and magnesium (Mg), and extraction of macrominerals (Table 5).

The highest N content was found in cv. Marandu (2.42%); this value was 2.03% in cv. Basilisk. Intermediate values were found in the cultivars Xaráes, Tanzânia, and *B. ruziziensis*. Based on grass requirements, the N content was within adequate levels (these range from 1.0 to 4.0%; Barnes et al., 2003).

Brachiaria ruziziensis had a higher K content (2.28%) than cv. Basilisk (1.73%); cvs. Marandu, Xaraés, and Tanzânia had intermediate values. The normal range for grasses according to Barnes et al. (2003) is from 2.0 to 4.0% of K. Based on this criterion, the K content in the Basilisk (1.73%), Xaráes (1.96%), and Tanzânia (1.99%) cultivars are close to, but below the normal range, albeit not at levels that could result in deficiency for these plants (less than 1%).

The mean values of P, Ca, and Mg in grasses were respectively 0.10, 0.27, and 0.23% (Table 5). The mean content of P (0.10%) was below ideal levels (from 0.25 to 0.5%) – this level would result in deficiency of P (<0.2%) (Barnes et al., 2003). However, visual symptoms of deficiency were not detected.

Possible explanations for a low P content in plants are low soil levels of P, and/or the presence of Cu and other contaminants (Table 6). Carneiro et al. (2001) found that grasses poorly absorbed P in areas contaminated by heavy metals; this was attributed to Zn, Pb, and Cd antagonism

Table 4 - Acid detergent fiber content (%) of the cultivars Basilisk, Marandu, Xaraés, Tanzânia and *B. ruziziensis* after three cuts

Cut	Basilisk	*B. ruziziensis*	Marandu	Xaraés	Tanzânia
1st	24.98aB	26.03aA	28.73aA	29.36aA	25.17aB
2nd	33.68aA	26.66bA	30.08abA	29.86abA	30.72abA
3rd	28.26abB	24.06bA	30.33aA	32.17aA	31.81aA

Means followed by the same letters (lowercase in rows and uppercase in columns) did not differ (P<0.05) by Tukey test. Coefficient of variation = 10.46%.

Table 5 - Dry matter yield, content and extraction of nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), and magnesium (Mg) in Basilisk, Marandu, Xaraés, Tanzânia, and *B. ruziziensis* in the second cut, and coefficients of variation (CV)

	Grass					Mean	CV%
	Basilisk	*B. ruziziensis*	Marandu	Xaraés	Tanzânia		
			Dry matter yield (kg ha^{-1})				
	1,886.03a	1,211.70a	1,369.80a	1,476.58a	1,478.66a	1,484.55a	36.80a
			Content (%)				
N	2.03b	2.12ab	2.42a	2.15ab	2.20ab	-	7.03
P	0.10a	0.08a	0.11a	0.09a	0.11a	0.10	21.19
K	1.73b	2.28a	2.00ab	1.96ab	1.99ab	-	11.78
Ca	0.23a	0.28a	0.32a	0.25a	0.29a	0.27	32.72
Mg	0.23a	0.18a	0.29a	0.26a	0.18a	0.23	22.93
			Extraction (kg ha^{-1})				
N	38.08a	25.81a	33.08a	31.63a	32.60a	32.24	36.40
P	1.98a	1.01a	1.65a	1.27a	1.61a	1.50	58.63
K	30.84a	27.58a	26.82a	28.86a	29.32a	28.68	31.13
Ca	4.32a	3.46a	4.67a	3.67a	4.53a	4.13	57.86
Mg	4.40a	2.29a	4.24a	3.86a	2.65a	3.49	53.53

Means followed by the same letters in rows did not differ (P<0.05) by Tukey test.

against absorption of P, suggesting that contamination negatively affected P content in the aerial portion of plants.

Calcium (Ca) levels were below the adequate range (0.5 to 2.0%, Barnes et al., 2003) in all species. The mean content of Mg (0.23%) was within the normal range (0.2 to 0.8%, Barnes et al., 2003).

Although the content of N and K were different between grasses, their extraction from plants – and that of the other minerals – did not differ between the forage grasses (Table 5). This may have occurred because of absence of the grass effect on the dry matter yield and/or the content of these minerals. The mean extraction values were 32.24 (N); 28.68 (K); 4.13 (Ca); 3.49 (Mg), and 1.50 kg ha^{-1} (P).

The content of chromium and nickel were different, and the content of zinc, cobalt, and lead were similar among grasses (Table 6).

The Cr concentration of cv. Basilisk (8.45 mg kg^{-1}) differed from that of cv. Marandu (0.28 mg kg^{-1}); *B. ruziziensis*, Xaraés, and Tanzania had intermediate concentrations (Table 6). Kabata-Pendias & Pendias (1992) considered the range of 75 to 100 mg kg^{-1} excessive for plants; these values are higher than the results in this study.

Cultivar Tanzânia had a higher Ni concentration compared with the other forage grasses (Table 6). However, Ni concentrations were higher than the normal range for grasses (0.2 to 2.0 mg kg^{-1}), but below toxicity levels (over 30 mg kg^{-1}, Barnes et al., 2003). Soluble Ni is readily absorbed by roots; it is mobile in plants and probably accumulates in leaves and seeds. The mean concentrations of the other heavy metals did not differ between grasses, and were 32.89 mg kg^{-1} (Zn); 3.51 mg kg^{-1} (Co), and 0.48 mg kg^{-1} (Pb) (Table 6).

The Zn concentration (Table 6) was within normal levels for the grasses (which is 10 to 100 mg kg^{-1}); toxic values are 200 mg kg^{-1} or more (Barnes et al., 2003). Zn is considered as having low to moderate phytotoxicity; it is commonly absorbed in higher amounts when it is available. Its concentration is usually higher in roots, but it may be translocated to the aerial portion of plants if present in excessive amounts (Kabata-Pendias & Pendias, 1992).

Silva et al. (2006) evaluated the growth of *Brachiaria decumbens* and its extraction capacity of Zn, Cd, Cu, and Pb from a contaminated soil, in greenhouse conditions and inoculated or not with arbuscular mycorrhizal fungi. In plants without arbuscular mycorrhizal fungi the mean Zn content was 1,511 mg kg^{-1} in dry matter within the aerial portion – a value quite above the toxic level for these plants. The normal range, according toKabata-Pendias & Pendias (1992) is 100 to 400 mg kg^{-1}.

Santos et al. (2007) studied phytostabilization by *B. decumbens* of a contaminated industrial waste (Zn and Cd) treated with different methods: industrial waste (control); industrial waste + 20% sludge; industrial waste + calcium silicate (2%; 3%); and [industrial waste + 20% sludge] + calcium silicate (2.5%; 4%). These authors noted that *B. decumbens* tolerated Zn and Cd in industrial waste after it had been treated by chemical containment. These studies suggested the potential that *B. decumbens* has for controlling and decontaminating environments; it thus may be a good alternative to reduce erosion and contaminant dispersion in the environment.

The mean value of Co was above the normal range for animals (the normal range is 0.05 to 2.0 mg kg^{-1}), but not toxic for plants (Barnes et al., 2003).

Lead (Pb) concentrations in the aerial portion of all species were below the phytotoxic range (30 to 300 mg kg^{-1}), as suggested by Kabata-Pendias & Pendias (1992). Pb occurs in plants but has no role in their metabolism. The extraction rate of Pb and Cr is limited by low inherent solubility (Nascimento & Xing, 2006). Silva et al. (2006) found that elevated soil concentrations of Pb did not increase its concentration in the aerial portion of *B. decumbens*, which confirms the low bioavailability of Pb in soils. Nevertheless, roots may absorb Pb and store it in cell walls; its translocation from roots to aerial portions is limited.

Copper (Cu) concentrations in forage grasses in decreasing order were as follows: Xaraés (7.48 ±7.98 mg kg^{-1}), Basilisk (4.50±1.12 mg kg^{-1}), *B. ruziziensis* (3.63± 0.73 mg kg^{-1}), Tanzânia (2.52±1.56 mg kg^{-1}), and Marandu (2.03±0.47 mg kg^{-1}). Cu concentrations were within or below normal levels (which

Table 6 - Concentration (mg kg^{-1}) of heavy metals such as chromium (Cr), nickel (Ni), zinc (Zn), cobalt (Co), and lead (Pb) in Basilisk, Marandu, Xaraés, Tanzânia, and *B. ruziziensis* in the second cut, and coefficients of variation (CV)

Heavy metal	Grass					Mean	CV%
	Basilisk	*B. ruziziensis*	Marandu	Xaraés	Tanzânia		
Cr	8.45a	4.15ab	0.28b	1.26ab	5.81ab	-	82.89
Ni	4.74b	4.33b	5.67b	5.20b	10.40a	-	20.24
Zn	27.61a	32.94a	40.52a	31.51a	31.89a	32.89	18.41
Co	3.36a	3.36a	4.27a	3.84a	2.70a	3.51	85.46
Pb	0.52a	0.52a	0.26a	0.54a	0.54a	0.48	108.53

Means followed by the same letters in rows did not differ (P<0.05) by Tukey test.

range from 5.0 to 15.0 mg kg^{-1}); toxic values are 20 mg kg^{-1} or over (Barnes et al, 2003). Silva et al. (2006) recorded 20.2 and 7.0 mg kg^{-1} in first and second cuts of *B. decumbens* cultivated in heavy metal contaminated soils. According to Kabata-Pendias & Pendias (1992), Cu is not readily mobile in plants; its translocation from the roots to the aerial portion of plants is slow, as it binds strongly to cell walls in roots.

Cadmium (Cd) concentrations in forage grasses in decreasing order were as follows: *B. ruziziensis* (0.5017 ±0.9897 ppm), Basilisk (0.2541±0.2902 ppm), Marandu (0.1582±0.3096 ppm), Xaraés (0.0077±0.0052 ppm), and Tanzânia (0.0052±0.0060 ppm); these values are much lower than the toxic level for these metals (5 to 30 ppm in dry matter) (Kabata-Pendias & Pendias, 1992). Silva et al. (2006) recorded a mean Cd concentration of 53 mg kg^{-1} in the aerial portion of *B. decumbens* that had been cultivated in contaminated soil.

Conclusions

Forage grasses had satisfactory dry matter yields, and are thus an alternative for rehabilitating areas degraded by urban solid waste. The concentration of heavy metals in these plants was below toxic levels, and the chemical-bromatologic composition was adequate, except for phosphorous. Rehabilitated areas in this manner may be used for grazing.

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